Fire Scar Detection using JERS, ERS and Radarsat Data in the Boguchany Area, Eastern Siberia

K.J. Ranson[1], K.Kovacs[2], G. Sun[3], and V.I. Kharuk[4]

[1] NASA's Goddard Space Flight Center, Code 923, Greenbelt, MD, USA, jon@taiga.gsfc.nasa.gov
[2] Science Systems and Applications, Inc. Lanham, MD, USA, kkovacs@forest.gsfc.nasa.gov
[3] Department of Geogrpaphy University of Maryland, College Park, USA, guoqing@aspen.gsfc.nasa.gov
[4] V.N. Sukachev Institute of Forest, Academgorodok, Krasnoyarsk, Russia, kharuk@forest.akadem.ru

***Abstract* – As part of a Siberian disturbance mapping project, this study evaluated the capability of three different radar sensors (ERS, JERS and Radarsat) to detect fire scars and logging in the boreal forest**.

Using Battacharrayya Distance analysis, this study found that the combined use of the three radar sensors achieved superior results in discriminating among fire and logging disturbance, however the success in discriminating forest types and burned and unburned stands was more limited.

1. Introduction

Until the early 1990's researchers have focused on using optical or thermal sensors to detect and map active fires and fire scars [1] [2] and [3]. These approaches relied on changes in temperature during fire and the vegetation changes immediately after the burn. References [4] and [5] found that ERS data could be used to detect fire scars in the boreal forest because the fire scars seem 3-6 dB brighter than the rest of the landscape. This brightness is a result of physical changes that occur due to fire including increased surface roughness, removal of tree canopies, and alteration of soil moisture patterns [6]. While optical and thermal sensors are sensitive to the initial changes in temperature and vegetative cover, SAR is sensitive to the longer-term roughness and moisture patterns that occur post-fire [6]. Kharuk and Ranson [7] found that both ERS and JERS backscatter was responsive to forest parameters, though other factors, principally surface moisture conditions often stronger have influence. According to [6] the burned area was not distinguishable from unburned forest using JERS data. They theorized that the lack of change on the L-band JERS images could be due to a lack of double bounce effect, or it could be due to the small size and geometry of the standing dead trees.

The purpose of this paper is to further investigate this issue by (1) analyzing JERS, ERS and Radarsat data to determine how energy is backscattered from vegetation types with a range of structural characteristics in order to (2) understand the mechanisms that govern these processes, and to (3) evaluate the potential of combined imaging radar data for detecting disturbance in the boreal forest.

2. Study Site

The Boguchany test site of the Siberian Disturbance Mapping project is located at 97deg 25' E and 59 deg 2' N, 75 km North of the Angara River and 350 km East of the Yenisey River in Eastern Siberia.

The test area, named after the nearby town of Boguchany that lies on the banks of the Angara River, is located within the Priangar'e region that is known as one of the most important sites for timber logging in Siberia [8]. Pine (Pinus spp.) and Larch species (Larix spp.) cover most of this landscape, however other conifers, such as Siberian pine (Pinus sibericus), Spruces (Picea spp.) and fir (Abies spp.), can also be found in patches in the area. Deciduous stands such as birch (Betula spp.) and aspen species (Populus spp.) cover the areas of lower elevation in this region. The elevation of the study site ranges from 300 to 500 m. The growing season in the region is short, ranging from late May to Early September. In the summer, smoke plumes from burning wild fires cloud the skies; fire is the principal factor that determines ecosystem dynamics in this region and therefore most of the stands are of pyrogenic origin [8].

Figure 1 Location of Boguchany site in Siberia

The fires that caused the burn scars in this study were ignited by lightening and extinguished by rainfall. This study will focus on the two largest fire scars in the area (See Fig. 2). Fire scar 1 is the product of two fires that were detected on the July 16 and 19, 1996 and merged into one fire the 21st of the same month. One of the two fires is known to have started on a great volume of dead wood, and regenerating pine, birch and aspen on a 1979 clear-cut. The fire was a strong surface and crown fire and by the time it was extinguished on August 8, 1996, 32 thousand hectares of forest, old clear cuts and dense regenerating stands were burned. The second fire contributing to fire scar 1 started in an approximately 100 year old pine-larch stand that also included some regenerating pine and larch trees. Fire scar 2 burned in an undisturbed coniferous forest 60 km northwest from fire scar 1 also in 1996.

3. Field Information

The fire scars were located using satellite imagery and verified by field surveys of the site in the fall of 1999 conducted by Scientist from the Sukachev Institute of Forest. Ground location was determined and survey plot measurements and photos were taken.

4. Data and preprocessing

4.1. Radar Data

JERS, ERS-1 and Radarsat data were analyzed to determine to what extent these different sensors could detect the presence of fire cars and clear cuts. Table 1 summarizes the most important parameters of these sensors.

The JERS data were received from NASDA in the spring of 1999 on a CD-ROM. The data were converted from slant to ground range and geocoded into the UTM projection by NASDA. At the Goddard Space Flight Center (GSFC) the data were resampled to 25 m pixel size, flipped, filtered using a 3 by 3 frost filter and reprojected to the Lambert Conformal Conic Projection (from here on referred to as LCC) with WGS 84 datum.

Table I. Radar sensor and image parameters

Sensor	JERS	ERS-1	Radarsat ST4
Frequency (GHz)	L band (1.275)	C band (5.3)	C band (5.3)
Wavelength (cm)	23.5	5.66	5.66
Polarization	HH	VV	HH
Inc. angle (deg)	38.9	23	34
Image Center	58.01N, 97.43E	97.55N, 59.49E	97.33N, 59.10 E
Orbital Direction	Descending	Descending	Ascending
Image Swath (km)	75	100	100
Altitude (km)	580	785	798
Data take date	March 31, 1997	June 7,1998	Aug 21, 1999
Pixel size (m)	12.5	12.5	12.5

The ERS-1 data were received from Alaska SAR Facility (ASF) in the spring of 1999 on a CD-ROM. These data were then multilooked to 25 m pixel size at GSFC, flipped, converted to ground range, wrapped onto a longitude/latitude grid using corner coordinates and, filtered using a 3 by 3 frost filter. They were then reprojected to LCC projection with WGS 84 datum.

The Radarsat standard beam data were received from ASF in January 2001 on 8mm tape in CEOS SAR file format. The data were previously converted to ground range by the ASF. At GSFC, the data were ingested, resampled to 25 m pixel size, wrapped into a longitude/latitude grid using corner coordinates and, filtered using a 3 by 3 Frost filter. They were then reprojected to LCC projection with WGS 84 datum.

There was no radiometric terrain correction applied to the radar images because the area did not have a steep topographic gradient (the elevation difference was less than 250 m).

4.2. Auxiliary Image Data

As auxiliary data, this project used Landsat 5 and Landsat 7 data. These optical data were used in conjunction with ground-based information such as maps, photos and local field knowledge to identify, ascertain and locate the different vegetation and burn classes and their training sites on the radar images.

Table II. Landsat sensor and image parameters

	Landsat 5	Landsat 7	Landsat 7
Data Take Date	Sept 3, 1991	Jul 31, 1999	Oct. 3, 1999
Image Center	58.71N,96.81 E	58.71N, 96.81 E	58.71N, 96.81 E
Path and Row	P141 R19	P141 R19	P141 R19
Resolution (m)	30	30	30
Sensor	TM	ETM+	ETM+
Cloud cover (%)	0	10	0
Bands	7	7 + pan	7 + pan

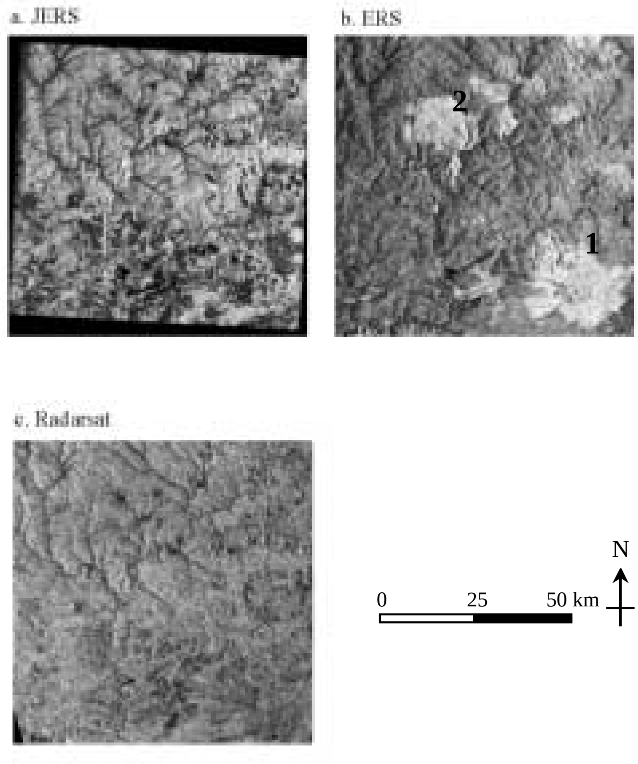

Figure 2.a The JERS image (LHH), b. ERS image (CVV) and c. Radarsat image (CHH) over the Boguchany site

The Landsat 5 data was ingested and reprojected from the WRS projection to the LCC projection with WGS 84 datum. The two Landsat 7 scenes were ordered and received from the EOSDIS DAAC in the summer of 2000 on 4 CD-ROMs, when they were ingested and reprojected from UTM projection to the LCC projection with WGS 84 datum.

To attain greater geometric accuracy and to ensure that the six data sets were co-registered with the highest possible accuracy, the JERS, ERS, Radarsat and Landsat 5 data were registered to the latest Landsat 7 scene. Landsat 7 was selected as geometric ground information for this site because it is know to be very well calibrated geometrically. According to [9] at the Goddard Space Flight Center, the absolute geodetic accuracy of Landsat 7 systematic product (generated without using ground control) is approximately 50 meters in the along and cross track directions, excluding terrain effects.

As it will be shortly explored, this project attempts to detect the signatures of relatively small anthropogenic features (clear cuts) with sharp, distinct edges. Using corner point-based registration alone, these edges (present in the JERS and Landsat 7 data) and rivers (present in all data sets) did not line up among the three data sets and the Landsat 5 and Landsat 7 scenes. This final manual registration step was necessary, we found, because radar data from 3 different sensors could not be co-registered using corner coordinates alone with a high level of geometric precision. Following the manual co-registration step, the data base was subsetted to the area covered by each of the 5 sensors. The size and extent of the JERS image determined this area, since this was the smallest image of all.

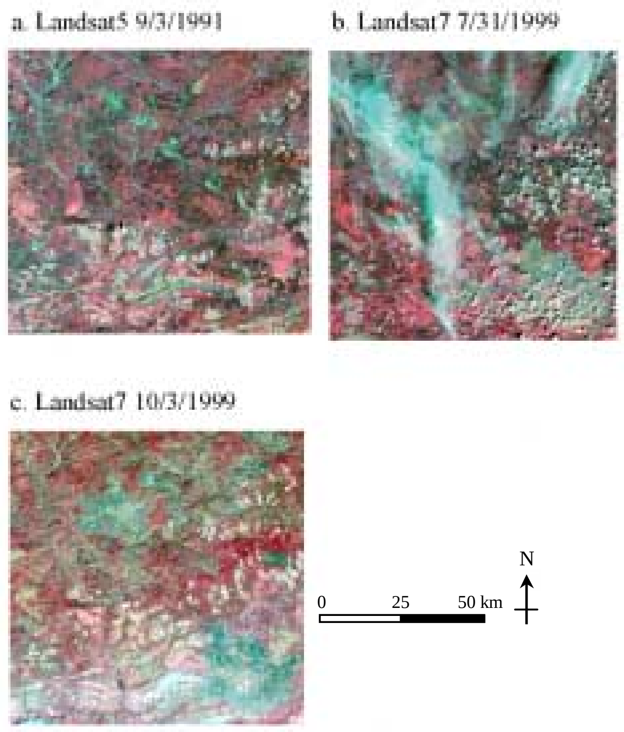

Figure 3.a Landsat 5 (9/31991), b. Landsat 7 (7/31/1999) and c. Landsat 7 (10/3/1999) Pseudo-color mages over the Boguchany area. Red=Band4 (NIR, 0.75 - 0.90 µm), Green=Band3 (Red, 0.63 - 0.69 µm), Blue=Band2 (Green, 0.525 - 0.605 µm)

4.3. Ground-based auxiliary Information

One field campaign was conducted into the Boguchany area by the staff from the Sukachev Institute in the fall of 1999. During this field campaign, tree species were identified. GPS measurements were acquired for use by Russian scientists. Plot measurements pertaining to the successional stages of the burned and logged areas were obtained. Also, approximately 50 photos were taken of mature healthy forests, logged and burned plots, post-cutting and post-fire regeneration. Information gathered during these field campaigns along with the existing local ecological knowledge of the staff at the Sukachev Institute of Forest provided a good basis for determining and locating the different vegetation classes on the Landsat and radar images.

5. Methodology

5.1. Determining vegetation classes

The purpose of the Siberian Disturbance Mapping Project is to map natural and anthropogenic disturbance in the boreal forest in accordance to widely used land cover classes to ensure the compatibility and comparability to other land cover products. Keeping this in mind, the vegetation classes for this study were determined based on the following criteria. The classes had to reflect the vegetation in the local landscape corresponding to the IGBP-DIS land cover classes and also to accommodate disturbed land cover as separate classes. Based on these criteria, the following vegetation classes were determined: *Coniferous forest (CF), Deciduous forest (DF), Regeneration/Sparse (RS), Clear cuts (CC), Burned coniferous forest (BC), Burned deciduous forest (BD), and Burned logged areas (BL).*

5.2. Training site selection

The training sites for these classes were determined based on the information gathered in the field, the multi-year and multi-season coverage provided by the three Landsat scenes and the contextual information provided by the individual Landsat scenes. In case of mapping recent disturbance, this temporal resolution was especially important because following disturbance the landscape can go through rapid change.

It is worth noting that if an unburned area is spectrally, structurally and texturally heterogeneous, it is likely that the fire scar visible in the landscape after burning will also be spectrally, structurally and texturally heterogeneous. This is to say that fire scars are not monolithic features at a 30m resolution and the patterns observable within a fire scar provide valuable information of the history of the site. When anthorpogenic disturbance (such a logging) has occurred in the area prior to the burn, the burned area will be a patchwork of spectral, structural and textural features shaped by a combination of anthropogenic and natural disturbance factors.

1. *Coniferous forest (CF)*

Coniferous forests in this area consist mostly of Pine (Pinus spp) and Larch species (Larix spp.), however other conifers, such as Siberian pine (Pinus sibericus), Spruces (Picea spp) and fir (Abies spp.), can also be found in patches.

Coniferous stands appear dark green in the summer and fall while deciduous trees change their color to bright yellow in the fall. The coniferous forest class was identified using the July and October 1999 Landsat 7 images and by detecting the coarser textures typical of forests and lower NIR reflectance values on the October image. On the October image, the deciduous trees were already turning yellow, which also aided this distinction.

2. *Deciduous forest (DF)*

Deciduous stands are composed of birch (Betula spp.) and aspen species (Populus spp.) in this region. The deciduous stands are green in the summer and turn bright yellow in the fall. This aided in identifying them on the July and October Landsat images.

3. *Regeneration/Sparse (RS)*

After a forest stand is clear cut, two scenarios are possible: either the site is abandoned and natural succession takes over, or pine seedling are planted at the site to ensure that the cut area will be covered by the next generation of pine trees. In both cases, there is a mixture of deciduous and coniferous seedlings will be found on the regenerating site. The regeneration/sparse site refers to areas that were logged over 10 years ago.

In the summer, young trees, seedlings and annual grasses are present on these sites. In the fall, these grasses die and the deciduous trees turn yellow. The post-clear cutting regeneration training sites was determined using 1991 and 1999 Landsat data and auxiliary data sources. On the 1991 September image (Figure 3a), clear cuts are clearly visible and stand out sharply from the surrounding forest. On the 1999 July (Figure 3c) and October image (Figure 4), the outlines of the same clear cuts are still visible, however one can also see that vegetation is growing on them.

Post clear cutting regeneration cannot be confused with post-fire regeneration if multi-date optical data is available simply because of the different spatial pattern of the two features. Post-clear cut regeneration sites, just like clear cut sites follow strict geometric shapes in this area, while post-fire regeneration seems to be cropping up in an irregular patchy fashion.

4. Clear cuts (CC)

The Boguchany area is one of the main timber logging areas in the region [8]. Several methods of logging are practiced in the region including the Finland technique, logging with seedlings preserved and complete clearing where no vegetation is left on the site. These sites are covered with live grasses in the summer and with dry, dead grasses in the fall. Freshly logged sites where soil is exposed were not included in the analysis because the date of cutting could not be determined

Training sites for the clear cut class was determined similarly to the post-clear cut regeneration class using the 1999 Landsat images. On clear cuts, part of the forest is missing in a geometric shape defined by sharp boundaries. In the summer, grasses grow on these sites and in the fall the grasses die and there is no live vegetation present on them. Clear cuts and fire scars are easy to separate since they have very different spectral characteristics and spatial patterns on the Landsat image. For example clear cuts have sharp edges and fire scars tend to be spread out features with no strait boundaries.

5. Burned coniferous forest (BC)

On forest sites burned by surface fires, as is the case in the fire scars studied here, dead tree trunks remain standing on the fire scar. In the summer live grasses grow underneath them these dead trunks, while in the fall, the grasses die and there is no significant live vegetation on the site.

Textural and contextual information along with field knowledge was used when determining the training sites for the burned coniferous class. For example, at times a coniferous forest stand may burn only partially. In this case there is good basis for comparison between the unburned and burned parts of the same stand.

6. Burned deciduous forest (BD)

Training sites for the burned deciduous forest stand were determined similarly to the previous class. Partially burned deciduous stands provide an opportunity to identify training sites for this class that would otherwise be difficult to locate based spectral information alone.

7. Burned logged areas (BL)

In the summer, live grasses and fire weed of the same height cover these sites. In the fall the grasses die and there is no live vegetation left standing on the site. Since these areas were previously cleared, there are no large dead tree trunks left standing on them like in the case of the burned forest sites.

Training sites for this class were determined using a combination of 1991 and 1999 Landsat 7 data. On the 1991 scene, geometric fields of regenerating clear cut sites and fresh clear cuts were clearly identifiable. By the time the 1999 scenes were acquired, these areas were burned.

Training sites for each class were chosen keeping in mind that the radar data available was acquired over a period of three years and the changes that have occurred within the landscape during this period had to be eliminated or at least minimized within the training sets. Some training sites were eliminated from the training set because on the 1991 Landsat 5 images they appeared as coniferous forest, and by the time the 1999 Landsat 7 scene was taken, the site became a clear cut. Since there was no additional information available on this particular site, it could not be determined at what point between the two dates the site was logged and whether or not the date of its logging fell within the three year period the radar data was acquired.

There was an effort made to keep the number of training sites within the same range for each class and also to keep the size of the training sites similar. This was done in order to ensure that there was no inherent statistical bias within the training set that might have lead to non-representative results. A table listing the number of training sites by class and the average size of the training sites is shown bellow.

Table III. Vegetation class and training set information

class	# of sites	# of pixels	avg. site size	class name
1CF	18	8483	471.28	coniferous forest
2DF	21	6318	300.86	deciduous forest
3RS	18	8320	462.22	Regeneration/sparse
4CC	21	6921	329.57	Clear cuts
5BC	18	6145	341.39	burned coniferous
6BD	17	5580	328.24	burned deciduous
7BL	18	9462	525.67	burned logged
total	131	avg.:	394.17	

Figure 4 The October 3, 1999 Landsat 7 scene with training sites Red=Band4 (NIR, 0.75 - 0.90 μm), Green=Band3 (Red, 0.63 - 0.69 μm), Blue=Band2 (Green, 0.525 - 0.605 μm). Bitmap colors: Red – CF, Green – DF, Blue – RS, Dark Purple – CC, Yellow – BC, Light Blue – BD, White – BL.

On the above table it can be seen that, despite the efforts to keep the sites the same size, for certain classes, such as post fire regeneration, this was not possible because this class was present on the image in relatively small patches.

5.3. Backscatter Analysis

The purpose of this analysis was to determine whether or not and how each sensor was detecting each land cover class and whether or not the radar sensors were capable of separating the classes from one another based on backscatter information alone. Once the training sites were carefully selected, backscatter information was extracted from each class for each radar sensor, and descriptive statistics were generated. The purpose of the Bhattacharyya Distance [10] and [11] analysis was to determine how each sensor was detecting each land cover class.

6. Results and discussion

6.1. JERS data

On table IV.a it can be seen that in the JERS data set the coniferous and deciduous forest classes, as well as the burned deciduous and coniferous forest classes have very similar brightness values. This is so probably because in the L band (0.23 m wavelength), larger tree branches and trunks are the primary scatterers and therefore this band is not sensitive to the presence or absence of the leaves, twigs or smaller branches which tend to burn easier than trunks. After surface fires, many of the tree trunks still remained standing as seen on the images of the burned forest sites. This might explain why the returns are so bright for both unburned and burned forest types in the L band. It is also clear that the regeneration sparse, clear cut and burned logged areas classes all have lower brightness values which is likely due to the absence of large branches and trunks.

Table IV. Descriptive statistics of vegetation classes for a. JERS, b. ERS and c. Radarsat data

a. JERS				
class	min	max	mean	std
1CF	168	201	186.480	4.930
2DF	162	207	188.897	6.792
3RS	146	194	163.837	6.734
4CC	128	204	157.772	9.467
5BC	152	202	183.669	6.788
6BD	170	203	189.460	4.727
7BL	127	194	156.190	9.788
b. ERS				
class	min	max	mean	std
1CF	172	212	191.315	6.410
2DF	170	210	192.193	5.204
3RS	163	208	185.959	7.286
4CC	162	225	191.330	8.801
5BC	191	231	210.113	7.450
6BD	191	220	207.178	4.688
7BL	169	234	199.160	8.989
c. RADARSAT				
class	min	max	mean	std
1CF	46	108	69.501	7.154
2DF	43	105	68.418	7.569
3RS	41	92	62.110	7.190
4CC	36	86	55.950	7.191
5BC	41	100	66.238	7.138
6BD	47	93	65.600	6.501
7BL	37	92	60.344	6.744

Table V.a shows the Bhattacharyya Distance values for all classes for the JERS data. (The three highest values are set in **bold** and the three lowest values are set in *Italics* to improve readability.) Maximum separability values exist between BL and BD classes (1.82988), and similarly high separabilities exist between RS and BD (1.82836), and CC and BD (1.81006) classes. The separability values between the other forested classes (CF, DF, and BC) and the non-forested classes (CC and BL) are also among the highest ones (ranging from 1.67315 to 1.73448). The separability was somewhat lower between RS and CF and DF classes. This indicates that forested classes and classes lacking tree cover are easily separable from each other using JERS data regardless of their burned state.

The lowest separability exists between the CC and BL class (0.00729) indicating that these non-forested classes are difficult to separate from the burned non-forested class. From this data it is clear that the JERS-1 LHH band alone cannot be used to discriminate:

(1) Between burned and unburned forest classes,
(2) Between deciduous and coniferous forest classes, and
(3) Between unburned and burned non-forested classes.

Table V. Bhattacharyya distance values for all vegetation classes. for a. JERS, b. ERS and c. Radarsat data and d. the three radar sensors combined

a. JERS

class	1CF	2DF	3RS	4CC	5BC	6BD
2DF	0.08982					
3RS	1.69000	1.64061				
4CC	1.70335	1.67315	0.18419			
5BC	0.10362	0.14285	1.31792	1.43440		
6BD	0.09375	0.06549	**1.82836**	**1.81006**	0.28641	
7BL	1.73448	1.70592	0.25738	*0.00729*	1.48847	**1.82988**
avg.	1.00416					
min	0.00729	CC&BL				
max	1.82988	BL&BD				

b. ERS

class	1CF	2DF	3RS	4CC	5BC	6BD
2DF	*0.02706*					
3RS	0.15426	0.27691				
4CC	*0.04877*	0.13117	0.12428			
5BC	1.19386	1.25715	**1.46971**	0.96922		
6BD	1.28004	**1.36510**	**1.57437**	1.03126	0.15709	
7BL	0.28593	0.33576	0.57140	0.18485	0.40392	0.45117
avg.	0.63301					
min	0.02706	CF&DC				
max	1.57437	RS&BD				

c. Radarsat

class	1CF	2DF	3RS	4CC	5BC	6BD
2DF	0.00699					
3RS	0.24866	0.17567				
4CC	**0.71996**	**0.60079**	0.17531			
5BC	0.05146	0.02353	0.08134	0.45449		
6BD	0.08581	0.05186	0.06726	0.43967	*0.00682*	
7BL	0.39136	0.29896	0.01802	0.09886	0.17374	0.14981
avg.	0.20573					
min	0.00682	BC&BD				
max	0.71996	CF&CC				

d. Radars combined

class	1CF	2DF	3RS	4CC	5BC	6BD
2DF	*0.12819*					
3RS	1.74129	1.69377				
4CC	**1.82178**	1.79706	0.49316			
5BC	1.26280	1.33321	1.84184	1.76733		
6BD	1.33342	1.41488	**1.93320**	**1.88794**	0.40797	
7BL	**1.88934**	**1.87803**	0.97153	0.33964	1.59521	**1.84749**
avg.	1.39900					
min	0.12819	CF&DC				
max	1.93320	RS&DBF				

However, JERS data can be used to discriminate:

(1) Between forest and non-forest classes regardless of burning,
(2) Between post-logging regeneration and forest classes regardless of burning.

6.2 ERS data

In Table IV.b it can be seen that the unburned classes (CF, DF, RS, and CC) all have lower brightness values than the burned classes (BC, BD, RS). The post-fire regeneration class seems to have intermediate values. C band radar is scattered by structures in about 5 cm in size such as leaves and small twigs on trees or grasses. As seen on the images of burned forest sites, small structures such as leaves and twigs are no longer presents on burned trees, however grasses having leaves of that sizes are abundant on the fire scar during the summer months. Based on this, the burned and unburned vegetation should be difficult to distinguish, however, this is not the case. There must be some other factor influencing the CVV backscatter that causes the burned areas to be brighter than the unburned ones. Reference [6] suggested that the reason why bright returns appear on fire scars on ERS images is that the soil moisture is higher on fire scars.

Table V.a shows the Bhattacharyya Distance values for all classes for the ERS data. The separability is highest (1.57437) between RS and BD classes, which is lower than the highest value was for the JERS data. Other class pairs with relatively high separabilities include RS and BC (1.46971), and DF and BD (1.36510). This indicates that post-cutting regeneration is easily separable from the burned forest classes. However, the separability between the RS and the unburned forest classes (CF and DF) is really poor (0.15426 and 0.27691, respectively).

Minimum separabilities are found between CF and DF classes (0.02706) indicating that CVV data cannot be used to distinguish between coniferous and deciduous forest classes. Separability values were also minimal between CF and CC (0.04877). From this data it is clear that the CVV band alone cannot be used to discriminate:

(1) between coniferous and deciduous stands,
(2) between clear cuts and forest classes, and
(3) between clear cuts and post fire regeneration classes.

However, ERS data can be used to discriminate:

(1) between burned and unburned land cover classes, regardless of other characteristics of the site,
(2) between post cutting regeneration classes and burned forest classes.

JERS data at the L-band seems to detect larger structural differences between forest types that are caused by logging (i.e. removal of large trunks). At the same time ERS C-band data seem to detect soil moisture differences (and perhaps structural and moisture differences at a leaf level associated with burning). This indicates that the combination of the two sensors should provide improved results in discriminating logged and burned areas.

6.3 Radarsat data

As seen in Table IV the different classes all seem to occupy one DN range. Only the clear-cut class has DN values that are a bit lower than the other classes.

Table V.c shows the separability values for the Radarsat data. The maximum separability is 0.71996 and it occurs between the CF and the CC classes. This value is quite low and indicates that the Radarsat data alone is not suitable for distinguishing any of these classes from each other. Other class pairs with similar separability values included DF and CC (0.60079).

There does not seem to be any obvious explanation as to why burned and unburned classes are so clearly separable using CVV ERS data and why the same classes are impossible to separate using CHH Radarsat data. Only one year passed between the acquisition of the two data sets, therefore land cover change is unlikely be the answer. There is a large, 11 degree difference in incidence angle between the two sensors, with ERS being 23 and Radarsat being 34 degrees, but it is not well understood exactly how incidence angle influences radar backscatter from burned areas. It is possible that at a higher incidence angle, the differences in soil moisture between burned and unburned areas are less pronounced.

7. JERS, ERS and Radarsat data combined

Table V.d shows the separability values generated based on the three sensor data combined. The average separability increased to 1.31881. Although this is an increase from using each sensor alone (JERS average separability: 0.94887, ERS: 0.56554, and Radarsat: 0.20237), on a whole, combining the three sensors does not provide very good distinction between these eight classes since separability values under 1.8 are considered poor. What is to be highlighted here, however, is the dramatic increase in the separability values of many of the classes when data from the three sensors were combined.

Maximum separability was found between RS and BD classes (1.93320) indicating that post clear-cutting regeneration and burned deciduous classes can be distinguished with good certainty. Similarly high separabilities were found between CF and RS (1.88934), CC and BD (1.88794), DF and RS (1.87803), BD and RS (1.84749), CF and CC (1.82178) just to list the classes with separabilities above 1.8. The common theme among these class pairs is that those classes can be separated successfully that have different structural characteristics determined by the presence or absence of large trunks and branches, such as forest and non-forest classes. This is mostly due to the LHH band JERS data, since these class pairs had reasonably high separabilities (around 1.7) using JERS data alone.

Minimum separabilities were found between CF and DF classes (0.12819) indicating that classes that have both large trunks and leaves present on them are not possible to separate using the three sensor data combined.

Figure 5 shows a pseudo-color image of the three radar sensors combined. The fire scars are shown as yellow, while the logged areas are visible as shades of green.

8. Conclusions

In this study we wanted to examine the utility of different radar systems for identifying forest landscape classes, especially those related to the main objective of our project, disturbance. We found that using single channel radars the results were limited, however JERS and ERS were found to be useful for identifying certain classes. Radarsat, on the other hand, was the least effective individual radar for this study. Combining the three radars improved the identification of classes over any single radar. This underscores the importance of using multichannel SAR data for forest studies. The future ALOS and ENVISAT and Radarsat 2 multichannel systems may contribute greatly to improved results in forest analysis and disturbance mapping.

Regarding the detection of disturbance, the available data was acquired over a two-year period so careful comparison of radars for burn scar detection was not possible. Changes in surface soil moisture can greatly change the backscatter from burn scars as shown by [5] and verified by other researchers. Acquisition date seems very critical for fire scar detection and characterization. We plan to continue to seek and analyze radar images acquired on similar dates to provide further information on this process.

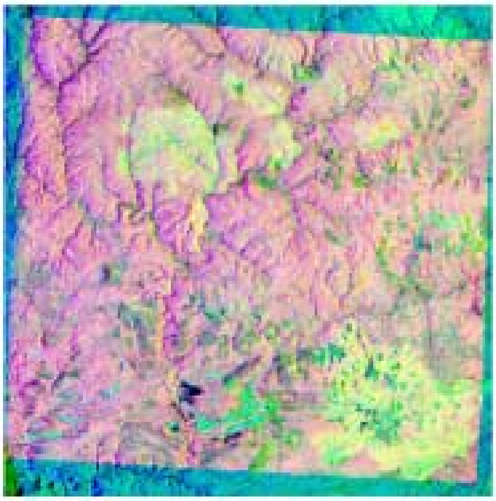

Figure 5. Pseudo-color image of the three radar images combined (Red = JERS, LHH; Green=ERS1, CVV; and Blue = Radarsat, CHH.)

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